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REVIEW ARTICLE

EFFECT OF AUGMENTED FEEDBACK ON MOTOR FUNCTION OF THE AFFECTED UPPER EXTREMITY IN REHABILITATION PATIENTS: A SYSTEMATIC REVIEW OF RANDOMIZED CONTROLLED TRIALS

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Objective: **Assessment of the available evidence regarding the effect of augmented feedback on motor function of the upper extremity in rehabilitation patients.**

Methods: **A systematic literature search was performed to identify randomized controlled trials that evaluated the effect of augmented feedback on motor function. Two reviewers systematically assessed the methodological quality of the trials. The reported effects were examined to evaluate the effect of therapeutic interventions using augmented feedback and to identify a possible relationship with patient characteristics, type of intervention, or methodological quality.**

Results: **Twenty-six randomized controlled trials were included, 9 of which reported a positive effect on arm function tests. Follow-up measurements were performed in 8 trials, 1 of which reported a positive effect. Different therapeutic interventions using augmented feedback, i.e. electromyographic biofeedback, kinetic feedback, kinematic feedback, or knowledge of results, show no difference in effectiveness.**

Conclusion: **No firm evidence was found of effectiveness regarding the use of augmented feedback to improve motor function of the upper extremity in rehabilitation patients. Future studies should focus more on the content, form and timing of augmented feedback concerning the therapeutic intervention. It should be emphasized that motor learning effects can only be determined by re-examining the population after a follow-up period.**

Key words: biofeedback, knowledge of results, motor skills, upper extremity, arm.

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INTRODUCTION

Feedback, along with practice, is considered to be a potent variable affecting motor skill learning (1, 2). When one performs a task, there are 2 general types of performance-related information, or feedback, available. One type of feedback is called "task-intrinsic" (or inherent) feedback, which is the sensory-perceptual information that is a natural part of performing a skill. For example, a person sees that he has missed picking up a cup with his hands. The second type of feedback is called "augmented" feedback. Although various terms have been used to identify this type of feedback (information, extrinsic or artificial feedback), the term that will be used in this review is augmented feedback. "Augmented" refers to adding to or enhancing task-intrinsic feedback with an external source (2, 3). The external source may be a therapist or a device such as a biofeedback system or a timer. This review focuses on the influence of augmented feedback on the performance and learning of motor skills.

Augmented feedback has been the focus of a large body of research (see Salmoni et al. (4) and Winstein (5) for reviews) and provides a fundamental cornerstone for motor learning theories. Substantial work has been conducted in which the effects of feedback variations such as content, form and timing have been studied (2, 3). Most of the research on which we base our knowledge of augmented feedback comes from laboratory experiments in which researchers gave augmented feedback to young, healthy participants. Typical tasks involved in these studies were simple and very contrived.

Augmented feedback, properly employed, may have practical implications for rehabilitation therapy since the re-acquisition of motor skills is an important part of functional motor recovery (5, 6). Some patients with cognitive and perceptual impairments are not able to use intrinsic feedback to guide their performance (7). Furthermore, because their own abilities to generate intrinsic feedback may be compromised by neurological sensory impairments, they may be more dependent on augmented feedback (8). However, a rehabilitation professional may find it difficult to implement the motor learning principles due to

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problems with generalizing the laboratory-based motor learning studies into a clinical setting (9).

Within the rehabilitation setting, therapeutic interventions are often aimed at improving motor function of the upper extremity. For example, loss of function of the affected upper extremity is a major problem after stroke (10). Also, patients with Parkinson's disease experience persistent difficulties with motor function of the upper extremity (11).

In recent decades, a number of articles have been published in which the effect of various rehabilitation methods using augmented feedback to improve arm function has been evaluated. Apart from many clinical studies of varying designs, several attempts have been made to synthesize the findings in reviews and meta-analyses. Most of these focus on 1 specific therapeutic intervention, such as EMG biofeedback (12–14). However, the present review focussed on the augmented feedback underlying a diversity of therapeutic interventions.

This present systematic review was performed to address the following research questions:

- What is the effect of therapeutic interventions using augmented feedback on motor function of the affected upper extremity in rehabilitation patients?
- Is there a relationship between the reported effects and patient characteristics, type of intervention, or methodological quality?

METHODS

Computerized literature searches were performed using MEDLINE (1966 – December 2004), EMBASE (1974 – December 2004), and Cochrane Controlled Trials Register (Cochrane Library Issue 1, 2004). The specialist rehabilitation research databases CIRRIE (Center for International Rehabilitation Research Information and Exchange; 1990 – December 2004) and REHABDATA (1956 – December 2004) were also searched. The CIRRIE database contains citations of international rehabilitation research. REHABDATA is an extensive database of disability and rehabilitation literature abstracts. The following key words were used: feedback, biofeedback, knowledge of results, reinforcement, cues, knowledge of performance, upper extremity, arm, upper limb, rehabilitation. The MEDLINE search strategy is outlined in Appendix 1. In addition, references to relevant publications were hand-searched.

Two reviewers (HvD and MJAJ) screened the titles and abstracts of the results of the literature searches independently. Trials that met the following criteria were included in the review:

- Therapeutic intervention applied to improve the motor function of the affected upper extremity in rehabilitation patients.
- Therapeutic intervention using augmented feedback.
- Outcomes measured at impairment and/or disability level.
- Randomized controlled trial (RCT).
- Published, full-length publication.

This systematic review only included RCTs because these are considered to have the most robust study design with the least risk of biased results. The reviewers did not apply any language restriction.

The publications that appeared to meet the inclusion criteria were retrieved and full-length publications were reviewed in further detail. In a consensus meeting, the 2 reviewers made the final decision on whether or not a publication should be included in the final review. In cases of disagreement, consensus was reached by discussion or, if necessary, by consulting a third reviewer (HJH).

The methodological quality of each included trial was assessed. A standardized quality scoring form (the Delphi list) containing 9 criteria was used to assess the randomization, treatment allocation, comparability between groups, eligibility criteria, blinding (of outcome assessor, care provider and patient), point estimates and measures of variability, and intention-to-treat analysis (see Appendix 2) (15). The 9 criteria could be rated as "do not know" if the available information was unclear or insufficient. If the available information was sufficiently clear, criteria were rated as "yes", indicating adequate methods, or "no", indicating inadequate methods or potential bias. Each "yes" was scored as 1 point, and therefore, a maximum of 9 points was possible.

The 2 reviewers (HvD and MJAJ) independently extracted data (methodological quality criteria, patient characteristics, type of intervention, outcome measures, and reported effects in the original publications) using a structured form. Blinding of the reviewers was not considered feasible because both reviewers already had considerable knowledge of the literature included in the review. Any differences of opinion were resolved by discussion or by the assistance of the third reviewer (HJH). Tables describing the included trials were generated. If necessary, trialists were contacted and requested to supply missing data. Concerning the therapeutic intervention, 4 different types of augmented feedback were reported: biofeedback, kinetic feedback, kinematic feedback and knowledge of results. The term biofeedback (BF) refers to an augmented form of feedback related to the activity of physiological processes within the body such as muscle activity (electromyographic (EMG) biofeedback) (2, 3). A detailed description of the movement pattern or response dynamics requires kinetic and/or kinematic feedback. Kinetic feedback parameters are obtained from the units of mass, force and time and often include impulse and peak force measures. Kinematic feedback parameters are derived from the dimensions of length and time and common kinematic parameters include displacement, velocity and acceleration values (16). Knowledge of results (KR) is a score presented to the performer as a representation of the outcome of the movement (2–4). This score often represented the error discrepancy between the performer's obtained response and some externally defined goal, although it can also be a representation of the actual outcome obtained.

The result of each trial was summarized as either "+" (positive for the experimental group, $p \leq 0.05$) or "0" (no difference, $p \geq 0.05$), according to the results presented in the original publications. In case of more than 1 reported effect (e.g. the experimental intervention consists of more than 1 group) the reviewers selected the most relevant comparison of groups according to the research question. An attempt was made to identify a relationship between reported effects and the following variables: patient characteristics (different diagnoses), type of intervention (different types of augmented feedback) and 2 methodological characteristics that have been shown to cause bias in the results of earlier reviews (concealed allocation of treatment and blinding of the outcome assessor) (17, 18).

RESULTS

The systematic search of the literature resulted in the identification of 33 publications, 27 of which fulfilled the selection criteria and were included in the present review (19–45). Six publications were excluded because these trials were not randomized. (A list of the excluded articles can be obtained on request from the first author.) In the 27 publications included in the review, 26 RCTs were described. The study characteristics and the methodological scores rated by the present reviewers are presented in Table I.

The number of patients included in a trial ranged from 9 (35) to 132 (40, 41). In 18 trials (19–23, 25–28, 32, 33, 35, 37, 39–41, 43–45), the study population concerned stroke patients. Other study populations were patients with traumatic brain injury (TBI) (24, 37, 45), spinal cord injury (SCI) (29–31), Parkinson's disease (PD) (34, 36, 38) and cerebral palsy (CP) (42). Platz et al. (36) used healthy subjects as controls.

Table I. *Characteristics of included randomized controlled trials and methodological scores*

Reference	Patients	Diagnosis	Age (years) Mean (SD)		Time post-onset Mean (SD)		Intervention – duration		Outcome measures[a]	Methodological score
			Experimental group	Control group	Experimental group	Control group	Experimental group	Control group		
Armagan et al., 2003 (19)	14E/13C	Stroke	57.0 (10.5)	57.9 (11.3)	4.4 mo (1.1)	4.8 mo (1.3)	EMG BF and conventional therapy – 5 sessions of 20 min per wk for 4 wk	Placebo EMG BF and conventional therapy – 5 sessions of 20 min per wk for 4 wk	Active ROM; Brunnstrom's stages of recovery; drinking from a glass; EMG activity	7
Basmaijan et al., 1982 (20)	Total $n = 37$; ?E/?C	Stroke	65 (40–79)	62 (48–74)	3.5 mo (2–6)	2.8 mo (2–5.5)	Integrated behavioural and physical therapy (including EMG BF) – 3 sessions of 40 min per wk for 5 wk	Conventional therapy – 3 sessions of 40 min per wk for 5 wk	UEFS; Minnesota rate of manipulation test; 9 hole peg test; Ontario society of occupational therapists test; grip and pinch	5
Basmaijan et al., 1987 (21)	13E/16C	Stroke	60.8 (8.5)	63.8 (13.1)	16.4 wk (7.6)	16.0 wk (11.7)	Integrated behavioural and physical therapy (including EMG BF) – 3 sessions of 45 min per wk for 5 wk	Conventional therapy – 3 sessions of 45 min per wk for 5 wk	UEFS; finger oscillation test	5
Bourbonnais et al., 2002 (22)	13E/12C	Stroke	47.2 (13.9)	44.6 (14.1)	37.3 mo (14.3)	34.7 mo (16.1)	Force feedback – 3 sessions per wk for 6 wk	No treatment	TEMPA; BBT; finger-to-nose test; shoulder and elbow strength; handgrip strength; FM; spasticity	4
Bowman et al., 1979 (23)	15E/15C	Stroke	?	?	Total: 3 wk–4 mo		Positional feedback stimulation training and conventional therapy – 2 sessions of 30 min per wkd for 4 wk (+ conventional therapy)	Conventional therapy – 5 d per wk for 4 wk	Active ROM; wrist extension torque	4
Croce et al., 1996 (24)	$14E^1/13E^2/12E^3/12C$	TBI	Total: 29.2 (8.2)		Total: 21.2 d (10.6)		E^1: KR on every trial E^2: summary KR E^3: average KR – 60 trials	No KR – 60 trials	Absolute constant error; variable error	3
Crow et al., 1989 (25)	20E/20C	Stroke	67.4 (10.5)	68.1 (9.5)	Total: 2–8 wk		EMG BF and conventional therapy – 6 wk	Placebo EMG BF and conventional therapy – 6 wk	Action research arm test; FM	6
Greenberg and Fowler, 1980 (26)	10E/10C	Stroke	63.3 (14.9)	66.5 (4.2)	3.3 yr (2.1)	3.0 yr (1.5)	Kinaesthetic BF – 2 sessions of 30 min per wk for 4 wk	Conventional therapy – 2 sessions of 30 min per wk for 4 wk	Active elbow extension	4

Hurd et al., 1980 (27)	12E/12C[1]/ 20C[2]	Stroke	59.4 (18.3)	C[1]: 55.8 (19.1)/C[2]: 54.8 (18.6)	74.5 d (54.5)	C[1]: 79.3 d (57.8)/ C[2]: 60.2 (42.8)	EMG BF and conventional therapy – ? sessions of 20 min for 2 wk (+ conventional therapy)	C[1]: simulated EMG BF and conventional therapy – ? sessions of 20 min for 2 wk (+ conventional therapy) C[2]: conventional therapy – 2 wk	Active ROM; passive ROM; EMG activity	6
Inglis et al., 1984 (28)	15E/15C; partial cross-over design	Stroke	59.6 (7.3)	61.9 (8.3)	22.8 mo (23.2)	14.4 mo (14.1)	EMG BF and conventional therapy – 20 sessions (4 blocks of 5)	Conventional therapy – 20 sessions (4 blocks of 5)	Active ROM; strength of muscle activity; picture goniometry; Brunnstrom's stages of recovery	4
Klose et al., 1993 (29)	14E/14C	SCI	26.4 (5.3)	24.3 (4.0)	Total: at least 1 yr		EMG BF, neuromuscular stimulation, and conventional therapy – 3 sessions of 1 h and 15 min per wk for 12 wk	Conventional therapy and neuromuscular stimulation – 3 sessions of 45 min per wk for 12 wk	Functional abilities measure; manual muscle test	4
Klose et al., 1990 (30)	10E[1]/10E[2]/ 9E[3]/10C	SCI	Total: ? (18–45)		Total: at least 1 yr		E[1]: EMG BF and conventional therapy E[2]: EMG BF and neuromuscular stimulation E[3]: neuromuscular stimulation and conventional therapy – 3 d per wk for 16 wk	Conventional therapy – 3 d per wk for 16 wk	Self-care score; mobility score; manual muscle test; EMG activity	4
Kohlmeyer et al., 1996 (31)	13E[1]/10E[2]/ 11E[3]/10C	SCI	E[1]: 38 (15)/E[2]: 32 (18)/ E[3]: 42 (15)	43 (18)	E[1]: 2.8 wk (1.0)/ E[2]: 3.2 (0.9)/ E[3]: 2.5 (1.0)	3.0 wk (0.9)	E[1]: EMG BF E[2]: functional electrical stimulation E[3]: EMG BF and functional electrical stimulation – 5 sessions of 20 min per wk for 5–6 wk	Conventional therapy – 5 sessions of 20 min per wk for 5–6 wk	Function score evaluation; manual muscle test	4
Lee et al., 1976 (32)	18E/18C[1]/ 18C[2]; cross-over design	Stroke	64 (?)	C[1]: 44 (?)/ C[2]: ? Total: 56.6 (31–79)	Total: 6 wk–7 yr		EMG BF – 20 contractions of 5 sec	C[1]: placebo EMG BF C[2]: conventional therapy – 20 contractions of 5 sec	EMG activity	3
Lum et al., 2002 (33)	13E/14C	Stroke	63.2 (3.6)	65.9 (2.4)	30.2 mo (6.2)	28.8 mo (6.3)	Robot-assisted movement training – 24 sessions of 1 h over 2 mo period	Conventional therapy – 24 sessions of 1 h over 2 mo period	FIM™ (self-care and transfer sections); BI; FM; shoulder and elbow strength; reaching ability	5

Table I. Continued

Reference	Patients	Diagnosis	Age (years) Mean (SD)		Time post-onset Mean (SD)		Intervention – duration		Outcome measures[a]	Methodological score
			Experimental group	Control group	Experimental group	Control group	Experimental group	Control group		
Marchese et al., 2000 (34)	10E/10C	PD	65.0 (5.8)	66.9 (6.3)	Total: 28–168 mo		Cued physical therapy – 3 sessions of 1 h per wk for 6 wk	Non-cued physical therapy – 3 sessions of 1 h per wk for 6 wk	UPDRS	5
Mroczek et al., 1978 (35)	9E/9C; cross-over design	Stroke	Total: ? (50–75)		Total: 1–10 yr		EMG BF – 3 sessions of 30 min per wk for 4 wk	Conventional therapy – 3 sessions of 30 min per wk for 4 wk	Active ROM; EMG activity	3
Platz et al., 1998 (36)	$7E^1/8E^2$/ $7C^1/8C^2$	PD	E^1: 65.9 (8.3)/E^2: 62.0 (14.6)	C^1: 62.1 (13.3)/ C^2: 60.8 (15.2)	E^1: 7.6 yr (2.6)/ E^2:4.3 (1.8)	*Healthy subjects as controls*	E^1: KR auditory rhythmic cues E^2: KR without auditory rhythmic cues – 100 trials	C^1: KR with auditory rhythmic cues C^2: KR without auditory rhythmic cues –100 trials	End-point accuracy; total movement time; movement duration; maximum tangential acceleration; maximum deceleration	4
Platz et al., 2001 (37)	$20E^1/20E^2/20C$	Stroke and TBI	E^1: 49 (17.9)/ E^2: 54 (18.0)	58.0 (15.3)	E^1: 6.1 wk (3.6)/ E^2: 6.2 (7.1)	10.3 wk (19.9)	E^1: arm ability training and conventional therapy E^2: KR, arm ability training, and conventional therapy – 32 min per wkd for 3 wk (+ conventional therapy)	Conventional therapy – ?	TEMPA; kinetically analysis of aiming movements	6
Shumaker, 1980 (38)	10E/10C	PD	65.2 (?)	67.2 (?)	10.7 yr (?)	12.6 yr (?)	Frontal EMG BF and progressive relaxation training – 1 session per wk for 15 wk	No treatment	General aptitude test battery (parts 9 placing test and 10 turning test)	4
Smith, 1979 (39)	6E/5C	Stroke	55.5 (40–67)	48.6 (22–67)	23.0 mo (7–69)	12.8 mo (6–30)	EMG BF – 2 sessions of 1 h per wk for 6 wk	Conventional therapy – 2 sessions of 1 h per wk for 6 wk	Brunnstrom's stages of recovery; audio-visual films	3
Sunderland et al., 1992, 1994 (41, 40)	$36E^1/29E^2$/ $35C^1/32C^2$	Stroke	E^1: 65 (32–88)/E^2: 67 (46–92)	C^1: 68 (50–82)/ C^2: 70 (35–84)	E^1: 8 d (2–35)/ E^2: 9 (1–31)	C^1:10 d (2–31)/C^2: 8 (0–29)	E^1: enhanced physical therapy (including EMG BF) – severe group E^2: mild group – median of 7 wk (0–33) of inpatient therapy; median of 11 wk (0–50) of outpatient therapy	C^1: conventional therapy – severe group C^2: mild group – median of 4 wk (0–48) of inpatient therapy; median of 6 wk (0–45) of outpatient therapy	BI; Frenchay arm test; 9 hole peg test; EMI; sub-tests of the motor club assessment; sensory loss; passive movement and pain	6

Talbot and Junkala, 1981 (42)	20E/19C[1]/20C[2]	CP	Total: 14 yr 3 mo (7–21)		?		Tracing with auditorally augmented feedback – 2 sessions of 10 min per d; a total of 40 sessions	C[1]: tracing alone – 2 sessions of 10 min per d; a total of 40 sessions C[2]: no tracing, no feedback —	SCMAT	4
Williams, 1982 (43)	10E[1]/10E[2]; cross-over design	Stroke	Total: 63.5 (11.8)		Total: 3–16 wk		E[1]: EMG BF and conventional therapy – 5 d of 20–25 min treatment (+ conventional therapy of 1 h) E[2]: relaxation therapy and conventional therapy – 2 d of 30 min instruction (+ conventional therapy of 1 h)	–	McGill Pain questionnaire (parts I to IV); passive ROM	5
Wolf et al., 1994 (44)	8E/8C	Stroke	63.9 (10.9)	62.0 (14.4)	32.6 mo (16.4)	65.5 mo (39.5)	EMG BF – 10 sessions of 25 min	Conventional movement training – 10 sessions of 25 min	Movement speed; active and passive ROM; EMG activity	4
Wolf et al., 1989 (45)	14E/12C	Stroke and TBI	54.7 (20.3)	46.0 (17.3)	Total: 1–7 yr		Motor copy (EMG BF) – sequence of 30 treatments	Conventional targeting training (EMG BF) – sequence of 30 treatments	Active ROM; functional tasks based on force or time measures; EMG activity	4

[a] Outcome measures not concerning the upper extremity were omitted.
E = experimental; C = control; SD = standard deviation; EMG BF = electromyographic biofeedback; min = minute(s); wkd = weekday; d = day(s); ROM = range of motion; UEFS = upper extremity functional scale; TEMPA = Test Évaluant la Performance des Membres supérieurs des Personnes Âgées; BBT = box-and-blocks test; FM = Fugl-Meyer assessment; TBI = traumatic brain injury; yr = year(s); KR = knowledge of results; SCI = spinal cord injury; PD = Parkinson's disease; FIM = functional independence measure; BI = Barthel index; UPDRS = unified Parkinson's disease rating scale; EMI = extended motricity index; CP = cerebral palsy; SCMAT = southern California motor accuracy test.

The type of therapeutic intervention varied between trials. Effects of EMG BF (19–21, 25, 27–32, 35, 38–41, 43–45), kinetic feedback (22, 33), kinematic feedback (23, 26) and KR (24, 34, 36, 37, 42) were described. In 4 trials, electrical stimulation (ES) was used to support the therapeutic intervention using augmented feedback; 3 were in addition to the EMG BF (29–31); 1 in addition to kinematic feedback (23). In 4 trials (19, 25, 27, 32), the experimental intervention EMG BF was simulated by offering the control group placebo EMG BF.

In most trials, 2 or more different outcome measures were applied (Table I). Five trials (26, 32, 34, 38, 42) only used 1 outcome measure (relevant for the upper extremity) to determine the effect of the experimental intervention. The most frequently used outcome measures were active (19, 23, 27, 28, 35, 44, 45) and/or passive (27, 43, 44) range of motion (ROM – 10 times) and EMG activity (7 times) (19, 27, 30, 32, 35, 44, 45). It was not always clear what the primary outcome measure was.

There was a disagreement between the 2 reviewers on 13 out of 234 (5.6%) of the items assessing the methodological quality. Consensus on these items was reached by discussion between the 2 reviewers, so the third reviewer was not consulted.

The scores for methodological quality ranged from 3 (24, 32, 35, 39) to 7 (19) out of 9 possible points. In all trials, a method of randomization was performed (although concealed allocation was only reported in 3 trials) (19, 37, 40, 41) and the eligibility criteria were specified. Groups were not similar (or the available information was unclear or insufficient) at baseline in 6 trials (22–24, 32, 35, 39). The outcome assessor was not blinded in 11 trials (22, 24, 26, 29, 32, 35, 36, 38, 42, 44, 45). In none of the trials was the care provider blinded. The blinding of patients was performed in 4 trials with the use of simulated/placebo EMG BF (19, 25, 27, 33). Point estimates and measures of variability were not presented for the primary outcome measures in 6 trials (23, 28, 30–32, 39). None of the trials described an intention-to-treat analysis.

The relationship between 4 study characteristics and reported effects (either summarized as "+" or "0") on motor function of the upper extremity is presented in Table II. These study characteristics are patient characteristics, type of intervention and the methodological characteristics concealed allocation of treatment and blinding of the outcome assessor. In 4 trials of the 26 RCTs, the obtained effects were not reported because no (relevant) statistical test was applied (24, 39) or the augmented feedback was used in both experimental and control group (36, 45). Follow-up measurements were performed in 8 trials (21, 22, 25, 33, 34, 37, 40–42).

Additionally in Table II, the contrast in duration of the exercise treatments was presented. In 7 trials (22, 23, 27, 29, 38, 40, 41, 43), there was a contrast in the duration of the exercise treatment between the experimental (E) and received control (C) intervention for the most relevant comparison of groups. In 3 of these 7 trials (23, 27, 40, 41), the reported result was positive in favour of the more intensive treatment. In 6 trials out of 15 (19, 25, 28, 33, 34, 42) without such a contrast in the duration of treatment, a positive effect for the therapeutic intervention was reported.

Table II shows there is no relationship between the reported effects and patient characteristics or type of intervention. Based on the distribution of the 22 RCTs according to the methodological criteria of concealment allocation and blinding the outcome assessor, there is no reason to suspect that the results were biased.

DISCUSSION

In this systematic review, the results of 26 RCTs were analysed in order to assess the effect of therapeutic interventions using augmented feedback on motor function of the affected upper extremity in rehabilitation patients and to identify a possible relationship between the reported effects and patient characteristics (different diagnoses), type of intervention (different types of augmented feedback) or methodological quality.

With regard to the first research question, the findings of this systematic review do not enable a definitive conclusion to be drawn about the effectiveness of therapeutic interventions using augmented feedback to improve upper extremity function in rehabilitation patients. Nine RCTs (19, 23, 25, 27, 28, 33, 34, 40–42) showed a positive (short-term or long-term) effect between treatment groups in favour of the applied intervention using augmented feedback and thirteen (20–22, 26, 29–32, 35, 37, 38, 43, 44) showed no difference between the applied interventions.

Several forms of bias could have influenced the results of the various trials, indicating that the results should be interpreted with caution. Firstly, a contrast in the duration of the exercise treatment is known to bias the results in favour of the more intensive treatment (46). There was a contrast in the duration of the treatment in 7 trials (22, 23, 27, 29, 38, 40, 41, 43), 3 of which (23, 27, 40, 41) reported a positive effect. This positive result is attributed to augmented feedback, but it might also be the result of longer duration of the treatment. Secondly, the results of this review might be biased due to the incompleteness of the intervention characteristics. Although the reviewers explicitly tried to extract this data using a structured form, the content, form and timing of the augmented feedback concerning the different types of intervention could often not be explored due to insufficient reported information. Motor learning research has proven that these factors have great influence on the performance and learning of motor skills (2, 3).

Motor skill learning can be defined as a set of internal processes associated with practice or experience leading to a relatively permanent change in the capability for movement (2, 3, 5). This rules out the changes in motor skills that can come from a variety of temporary performance factors. It is therefore remarkable about the presented trials that only 8 RCTs (21, 22, 25, 33, 34, 37, 40–42) performed a follow-up measurement to determine if the improvement in motor function of the upper extremity lasted after a period of non-therapy. Of these 8, only the study of Marchese et al. (34) showed a positive

Table II. *Relationship between reported effects of the augmented feedback on arm function and study characteristics*

References	Reported effect[a]	Contrast in duration of treatment[b]	Patient characteristics	Type of intervention	Concealment of allocation[b]	Blinding of outcome assessor[b]
Shumaker, 1980 (38)	0	+	PD	EMG BF	−	−
Klose et al., 1993 (29)	0	+	SCI	EMG BF	−	−
Klose et al., 1990[c] (30)	0	−	SCI	EMG BF	−	+
Kohlmeyer et al., 1996[d] (31)	0	−	SCI	EMG BF	−	+
Basmaijan et al., 1982 (20)	0	−	Stroke	EMG BF	−	+
Basmaijan et al., 1987 (21)	PT0, FU0	−	Stroke	EMG BF	−	+
Lee et al., 1976 (32)	0	−	Stroke	EMG BF	−	−
Mroczek et al., 1978 (35)	0	−	Stroke	EMG BF	−	−
Williams, 1982[e] (43)	0	+	Stroke	EMG BF	−	+
Wolf et al., 1994 (44)	0	−	Stroke	EMG BF	−	−
Bourbonnais et al., 2002 (22)	PT0, FU0	+	Stroke	Kinetic feedback	−	−
Greenberg and Fowler, 1980 (26)	0	−	Stroke	Kinematic feedback	−	−
Platz et al., 2001[e] (37)	PT0, FU0	−	Stroke and TBI	KR	+	+
Armagan et al., 2003 (19)	+	−	Stroke	EMG BF	+	+
Hurd et al., 1980[f] (27)	+	+	Stroke	EMG BF	−	+
Inglis et al., 1984 (28)	+	−	Stroke	EMG BF	−	+
Sunderland et al., 1992, 1994 (41, 40)	PT0, FU0	+	Stroke	EMG BF	+	+
Crow et al., 1989 (25)	PT0, FU0	−	Stroke	EMG BF	−	+
Lum et al., 2002 (33)	PT0, FU0	−	Stroke	Kinetic feedback	−	+
Bowman et al., 1979 (23)	+	+	Stroke	Kinematic feedback	−	+
Talbot and Junkala, 1981[g] (42)	PT0, FU0	−	CP	KR	−	−
Marchese et al., 2000 (34)	PT0, FU+	−	PD	KR	−	+

[a] Effect reported in original publication on outcome measure selected as primary by the authors/reviewers; PT = post-test; FU = follow-up.
[b] "+" means yes; "−" means no/do not know.
[c] E^1 and E^2 compared with C.
[d] E^1 and E^3 compared with C.
[e] E^1 compared with E^2.
[f] E compared with C^2.
[g] E compared with C^1.
PD = Parkinson's disease; SCI = spinal cord injury; TBI = traumatic brain injury; CP = cerebral palsy; EMG BF = electromyographic biofeedback; KR = knowledge of results.

motor learning effect (i.e. a relatively permanent effect after a period of non-therapy) of the experimental intervention (using KR) in comparison with the control group. In this study, the clinical improvements in the "non-cued" group had faded at 6 weeks post-treatment, while in the experimental "cued" group the improvements still endured. Four of the 8 RCTs (25, 33, 41, 42) showed a lack of persistence of the gained difference between the treatment groups. This might be caused by short, low-intensity treatment periods. For a therapeutic intervention to be fully effective, the treatment/therapy has to be of sufficient duration and intensity (46).

With regard to the second research question, no firm relationship could be identified between the reported effects and patient characteristics or type of intervention. Identification of groups of patients, who might be more likely to benefit from a specific type of intervention, was difficult because of the heterogeneity of the trials. Different types of interventions using augmented feedback, i.e. EMG BF, kinetic feedback, kinematic feedback, or KR, have shown no difference in effectiveness.

Meta-analysis is a statistical technique for increasing the power of the clinical outcome data by pooling individual trial outcomes (47). It was not possible to perform a meta-analysis of the findings of different RCTs resulting in a single summary effect size. The selected trials were too heterogeneous with regard to patient characteristics and type of intervention. It was therefore decided to refrain from performing a pooled analysis in this review. Moreover, the focus of the present review was on the augmented feedback underlying the therapeutic intervention. The heterogeneity of the included trials was expected as the inclusion criteria did not focus on patient diagnosis or therapeutic intervention. Concerning the specific therapeutic intervention EMG BF 3 meta-analyses are available that assessed the efficacy of biofeedback therapy in post-stroke rehabilitation (12–14).

Regarding the methodological quality of the included RCTs in relation to the reported effects, it is noticeable that the methodological score (rated by the 2 reviewers) is slightly higher for the trials reporting a positive effect in favour of the experimental treatment in comparison to the trials reporting a negative effect (i.e. mean score of 5.2 for trials reporting a positive effect and 4.2 for trials reporting a negative effect). This higher score is largely attributable to the blinding of the outcome assessor (Table II). One might expect that blinding the outcome assessor decrease the opportunity for a positive effect to occur since the assessor is likely to favour the experimental treatment. This is however not the case in the present review. The authors did not find an explanation for this.

The methodological scores are generally low (a score of 3 or 4 out of 9) for the majority of the included trials (15 trials out

of the total of 26 trials). Future studies should more consider the concealment of treatment allocation, the blinding of care providers and patients, and an intention-to-treat analysis as design requirements.

Although augmented feedback is widely regarded as a critical variable in the (re)acquisition of motor skills, no firm evidence was found of the effectiveness of the use of augmented feedback to improve arm function in rehabilitation patients in the present review. This does not imply evidence of no effect. Winstein (5) suggested that it is appropriate to use the principles of motor learning obtained through laboratory experimentation as guidelines when applying basic research findings to clinical practice. However, given the insufficient reported information in the included publications, it is not yet possible to formulate to what extent these principles of motor learning (regarding the use of augmented feedback) are properly employed. Future studies should focus more on the content, form and timing of the augmented feedback in order to clarify its importance. Also, more studies should recognize the difference between performance and learning effects concerning the (re)acquisition of motor skills by re-examining the study population after a follow-up period.

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APPENDIX 1

MEDLINE search strategy

#1 Feedback [MeSH]
#2 Biofeedback [MeSH]
#3 Knowledge of results [MeSH]
#4 Reinforcement [MeSH]
#5 Cues [MeSH]
#6 Knowledge [tw] AND Performance [tw]
#7 Upper extremity [MeSH]
#8 Arm [MeSH]
#9 Upper limb [tw]
#10 Rehabilitation [MeSH]
#11 #1 OR #2 OR #3 OR #4 OR #5 OR #6
#12 #7 OR #8 OR #9
#13 #10 AND #11 AND #12 AND Randomized controlled trial [pt]
#14 #13 AND Human [MeSH]

APPENDIX 2

The Delphi list

1. Was a method of randomization performed?
2. Was the treatment allocation concealed?
3. Were the groups similar at baseline regarding the most important prognostic indicators?
4. Were eligibility criteria specified?
5. Was the outcome assessor blinded?
6. Was the care provider blinded?
7. Was the patient blinded?
8. Were point estimates and measures of variability presented for the primary outcome measures?
9. Did the analysis include an intention-to-treat analysis?